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Fine Aggregate Angularity Effects on Rutting Resistance of Asphalt Mixture

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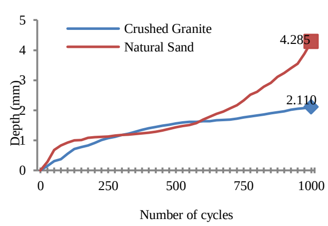
Graphical abstract



Abstract

Fine Aggregate Angularity (FAA) has been identified as one of the important aggregate properties contributing to the stability of Hot Mix Asphalt (HMA) and its resistance against permanent deformation. The performance of dense graded asphalt mixture is significantly influenced by the shape, angularity and surface texture of fine aggregates. This study determines the FAA for different types of aggregates namely granite and natural sand and evaluates the rutting resistance of AC 10 mixture added with the aforementioned aggregates. Marshall test and wheel tracking test were carried out in order to assess stability and rutting resistance. It was found from FAA test, crushed granite has higher percentage of FAA (46%) compared to natural sand (37%). With higher FAA value, crushed granite mix was found to have better stability, stiffness, and flow compared to specimen with natural sand. From wheel tracking test, it was observed that the rut depth for specimen with crushed granite is lower compared to specimen with natural sand. Therefore it can be concluded that fine aggregates with more angular shape, provides better stability and increase the rutting resistance.

Keywords: Fine aggregates; fine aggregate angularity; AC10; Marshall properties; rutting

1.0 INTRODUCTION

In asphalt mixtures, aggregate particles usually comprise between 94 to 96 percent by mass of the total mix with approximately 40 percent is fine aggregate (passing 2.36 mm or No. #4 sieve). The quality and quantity of fine and coarse aggregates play a very important role in asphalt mixture. For instance, the geometric irregularity of both coarse and fine aggregate has a major effect on the volumetric properties and performance of asphalt mixtures which include stiffness, stability, durability, permeability, resistance to moisture damage, resistance to rutting and total air voids in the mixture[1]. This geometric irregularity can be attributed to the aggregate particle shape, angularity, and surface texture. Asphalt mixture with rounded, nonporous, smooth-textured aggregate particles prone to be more susceptible to rutting. Angular, slightly porous, rough-textured particles should maximize the resistance of HMA mixtures to rutting. Angular particles is a property found in most crushed stone, provide a better interlocking characteristic than rounded aggregate particles[2]. Previous studies have identified that rutting occurs as a result of accumulated plastic deformation due to high traffic loads and high temperatures[3]. It occurs when road does not have sufficient stability of the asphalt material at the surface layer, insufficient compaction of the pavement and insufficient pavement strength. Use of poorly graded aggregates having smooth, rounded particles and a high percentage of rounded sand has contributed to the loss of shearing resistance of asphalt concrete mixtures[4]. Button *et al*. studied the influence of aggregate on rutting of asphalt pavement. They noted that the main factors associated with rutting were excessive bitumen content, excessive fine aggregate, and the rounded shape and smooth texture of uncrushed aggregate particles[5]. A number of research has been conducted on the effect of aggregate shape and surface texture of the fine aggregates on asphalt mixture performance[6]. Herrain and Goetz reported the effect of aggregate shape on stability of bituminous mixtures. They concluded that the addition of crushed gravel in the coarse aggregate increased the strength for single size aggregate mixture[7]. Later, Lottman and Goetz reported the effect of crushed gravel fine aggregate on strength of asphalt surface mixtures and concluded that the increased strength of bituminous surface mixtures made with crushed gravel fine aggregate when compared to similar mixtures made with natural-sand fine aggregate, was thought to be due to the angularity and surface texture of the crushed aggregate[8]. Wedding and Gaynor studied the effects of using crushed gravel in asphalt mixture. They found that the replacement of natural sand with crushed fines improves the properties of the product for instance increases its stability, reduces rutting and improves water-resistance[9]. On the other hand, replacement of the coarse material with crushed coarse aggregate entails no such effect. Kalcheff and Tunnicliff studied the effects of crushed stone aggregate size and shape on properties of asphalt mixture. The results indicated that mixtures containing crushed coarse and fine aggregate have higher resistance to permanent deformation as a result of repeated loading, and less susceptibility to the effects of temperature and higher initial void content compared to mixtures containing natural sand[10]. These findings prove that the quantification of aggregate geometric irregularities is important to understand their effects on pavement performance in order to produce pavements with adequate quality. Recently, Yasreen *et al*. found that the higher the values of fine aggregate angularity (FAA), the more angular are the particles with rougher surface texture. This resulted in a better interlocking mechanism between the particles and thus offering better shear strength[11]. Therefore, this study was focused on comparing two types of fine aggregates which were crushed granite and natural sand. Crushed granite was the conventional material that is normally used in road construction. FAA value was used to describe the particle shape and surface texture of fine aggregates. Both fine aggregate types later were added into dense graded asphalt mixture (AC10) and the mixtures were evaluated for rutting resistance.

2.0 MATERIALS AND METHODS

2.1 Bitumen

Penetration grade bitumen 80/100 PEN was used in this study. The properties of bitumen were investigated using Penetration and Softening Point tests. Table 1 shows the results of the bitumen properties and the specification.

Table 1 Binder properties

Properties	Specification for 80/100 (JKR/SPJ/2008-S4)		Result from tests
	minimum	maximum	
Penetration	80	100	90
Softening Point	45	52	48

2.2 Aggregates

The aggregates were supplied by MRP Quarry, Johor. Two types of fine aggregate (size less than 1.18mm) were chosen for the evaluation, crushed granite and natural sand (Figure 1). Granite and hydrated lime (calcium hydroxide) were used as coarse aggregate and filler respectively. The aggregate gradation was designed based on dense graded; AC10 according to JKR specifications. Figure 2 shows the designed aggregate gradation for AC10 mixture.

(a) (b)

Figure 1 (a) Natural river sand (b) Crushed granite

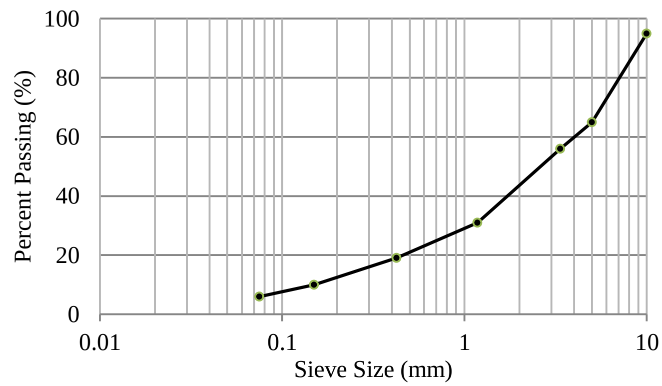


Figure 2 Design aggregate gradation for AC 10

2.3 Mixture Design

This procedure determines the optimum bitumen content using the Marshall mix design method in accordance to JKR/SPJ/2008-S4[12]. The parameters include stability, density, flow, stiffness, voids in total mix (VTM), and voids filled with bitumen (VFB) were measured and compared to the specification.

2.4 FAA Test

This test was conducted on both fine aggregates in accordance to ASTM C1252-06[13] to estimate the aggregate angularity by measuring the loose uncompacted void content. Figure 3 shows the preparation of apparatus before the test. When performing this test on an aggregate sample with a known standard grading, the measurement provides an indication of particle shape. The material's angularity, roundness or surface texture is indicated by the percent of voids determined by this test with an assumption that, the higher the void content, the higher the angularity and rougher the surface of fine aggregate. The value of FAA was calculated using Eq. 1.

$$FAA = \left[\frac{(V-(\frac{F}{G})}{V}\right] x\ 100\% \qquad \text{(Eq.1)}$$

Where:

V = volume of calibrated cylinder in mL
F = net weight of sample in cylinder
G = bulk dry specific gravity of the particle
FAA = uncompacted voids in percent (to the nearest 0.1%)

Figure 3 FAA test apparatus

2.5 Wheel Tracking Test

Two slabs were prepared for each mixture type with the size of 300x300x50mm at the optimum bitumen content 5.9% and 6.1% for crushed granite and sand respectively. Trial and error method was carried out in order to determine the number of roller passes for compaction purposes. The degree of compaction (doc) is measured by the ratio of specific gravity of Marshall properties to the specific gravity of rutting sample. It was found that both doc met the required specification by JKR/SPJ/2008-S4 for binder course of pavement. Wessex Dry wheel tracking test (as shown in Figure 4) was used to measure the rutting resistance of the mixture. The test was conducted according to BS EN 12697-22:2003 specification. The rut depth was recorded at every 25 load cycles. Based on the specification, the sample was considered to reach failure if the rut depth exceeds 15 mm. The test was terminated at 1000 load cycles. Figure 5 shows the slab was positioned in the machine and ready to be tested. The total rut depth was recorded by the Wessex software that comes together with the machine. The testing procedures conform to the specification of BS EN 12697-22:2003[14].

Figure 4 Wessex dry wheel tracking machine

Figure 5 Sample placed on Wessex wheel tracking machine

3.0 RESULTS AND DISCUSSION

3.1 Effect of FAA on Marshall Properties

Table 2 shows the result of the specific gravity and FAA value for each material. From the test, the value of FAA for crushed granite is higher than natural sand. The percentages of uncompacted voids are 46% and 37% for crushed granite and natural sand accordingly. Thus, the higher the values of fine aggregate angularity, the more angular the particles with rougher surface texture.

Table 2 FAA value for crushed granite and natural sand

Material	Net weight of sample, F (g)	Specific gravity, G	FAA value (%)
Crushed granite	142.6	2.66	46
Natural sand	161.4	2.56	37

The shape and surface texture of aggregate affect the asphalt mixture properties which include stiffness, stability, durability, permeability and air voids in the mixture. Additionally, it affects the workability of the mixture at optimum bitumen content. It was found that the optimum bitumen content for crushed granite and natural sand mixture is 5.9% and 6.1% accordingly. At these bitumen contents, mixture with crushed granite contain smaller VTM compared to mixture with natural sand. In other words less OBC needed for the crushed granite mixture to achieve the low air voids content that could be as a result of the better aggregate interlocking. From the test, crushed granite mixture has greater values of stability and stiffness than mixture with natural sand (as in Table 3). Higher stiffness as indicated by the higher stability shows that the mixture has greater resistance against permanent deformation. Stiffness of mixture indicates the interlocking behavior of the mixture. Higher the stiffness produced better interlock in mixture hence resulting to better performance of the pavement. This is supported by the higher value of VFB which describes the good bonding or better aggregate coating that will give better stability.

Table 3 Comparison of Marshall properties and specification

Marshal properties	Specification (JKR/SPJ/2008-S4)	Materials	
		Crushed granite	Natural river sand
Voids in total mix (VTM)	3-5%	3.1	5.1
Stability	>8000N	16908	16056
Flow	2 - 4 mm	3.33	3.66
Voids Filled with bitumen (VFB)	70-80%	79.5	72.4
Stiffness	>2000N/mm	4415	3908

(a)

(b)

Figure 6 Slabs with rutting for (a) mixture with crushed granite (b) mixture with sand

3.2 Effect of FAA on Rutting Resistance

The results show that after 1000 load cycles, sample with crushed granite reached 2.11 mm whereas sample with natural sand reached 4.285 mm. Figures 6 and 7 show the samples after testing with the rut depth and graph of the rut depth versus the load cycles for both mixture types. The rut depth of the mixture with natural sand initially increased from 0 to 300 cycles compared to crushed granite. At the range of 300 to 575 cycles the rut depth for natural sand is lower than crushed granite. After 600 cycles the behavior of rut depth for natural sand rapidly increased until 1000 cycles. The behavior of rut depth for crushed granite ~~is~~ gradually increased from 0 to 1000 cycles. Based on the trends of the rut depth, it can be concluded that crushed granite mixture have better rutting resistance than the mixture with natural sand as a result of the 'stone to stone interlocking' of the angular particles which provides higher shear strength to withstand the rutting. In addition the rougher surface texture of the crushed granite has contributed to the better rutting resistance compared to natural sand with smooth surface and rounded shape.

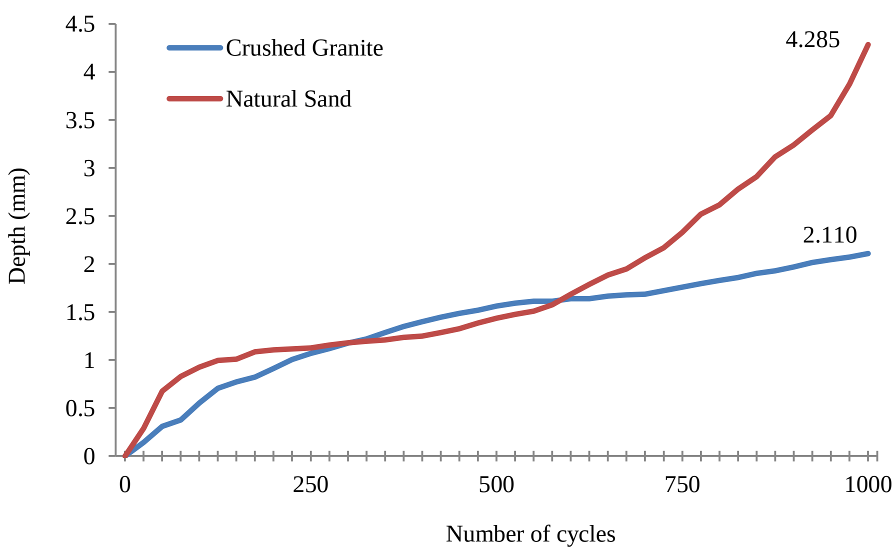


Figure 7 Measurement of rut depth for mixtures containing crushed granite and natural sand

4.0 CONCLUSIONS

From this investigation, it can be concluded that the fine aggregate angularity of crushed granite is higher than natural sand. The percentages of uncompacted voids are 46% for crushed granite and 37% for natural sand due to the shape irregularities and surface texture. This shows that natural sand has less weight of sample due to higher voids content compared to crushed granite. Thus, the higher the values of fine aggregate angularity, the more angular the particles with rougher surface texture. As a result of the greater angular shape, AC10 mix with crushed granite produce lower rut depth compared to mix using natural sand. Therefore, fine aggregates with higher value of aggregate angularity in asphalt mixture improve the rutting resistance. This proves that the use of angular aggregates in asphalt mixture provides better performance particularly less potential of rutting under repetitive loading.

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